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The mechanism behind environmental inequality in Scotland: which came first, the deprivation or the landfill?

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ABSTRACT

Research suggests that people living in deprived areas of the UK are more likely to be exposed to hazardous environments than those in more affluent areas, but the mechanism behind this trend is not clear. Discrimination in the siting of undesirable land uses has often been blamed, leading to claims of environmental injustice. However, environmental inequalities may also arise through post-siting processes that lead to selective migration: the presence of an undesirable land use may devalue local property, encouraging affluent households to move away and deprived households to move in to surrounding areas. Ascertaining the underlying process at work is important as this has significant implications for guiding policies aimed at delivering environmental justice.

We investigated the distribution of municipal landfill sites in Scotland and local exposure to their airborne emissions. GIS techniques were used to construct a wind-, emissions- and distance-weighted model with which small-area exposure to landfills could be classified. This model gave the exposure classification a degree of realism not generally incorporated in similar studies. We found clear evidence of environmental inequality: socially deprived areas of Scotland are disproportionately exposed to municipal landfills and have been since at least 1981. We then asked which came first, the deprivation or the landfill? Our results suggest that both disproportionate siting and post-siting market dynamics may play a role: area deprivation may have preceded disproportionate landfill siting to some extent, particularly in the 1980s, but landfill siting also preceded a relative increase in deprivation in exposed areas. Areas that became exposed to a municipal landfill in the 1980s were subsequently 1.65 times more likely to be classified as deprived by 2001 than areas that remained unexposed.

Key words:

Environmental inequality, landfill, Scotland, deprivation, GIS

INTRODUCTION**Environmental inequality**

Environmental hazards are often distributed unevenly in space (e.g., McLeod et al., 2000; Mitchell and Dorling, 2003). In the US, research has revealed evidence that racial minorities are disproportionately burdened with environmental disamenities (e.g., Cutter, 1995; Pastor et al., 2001). In the UK, research has tended to focus on inequalities with respect to socioeconomic deprivation, showing that people living in deprived areas are more likely to be exposed to hazardous environments than those in more affluent areas (e.g., Brainard et al., 2002; Walker et al., 2005; Wheeler, 2004).

Whether an environmental inequality constitutes an environmental injustice will depend upon whether the processes that created the distribution were inequitable (Schlosberg, 2007; Walker et al., 2005). Despite the growing body of evidence for environmental inequalities worldwide, the processes by which these have arisen often remain unclear. Without knowledge of the causative factors policy interventions are unlikely to result in long-term solutions (Lambert and Boerner, 1997; Liu, 2001).

The unequal distribution of population and environmental risk can be viewed from the perspective of economic and location theories: as economic agents firms seek to maximise their profits and households seek to maximise their utility, and their locational choices reflect these aims. Undesirable land uses (e.g., landfills, factories) may be sited in places where

collective action against them and compensation claims are likely to be minimised, and lower quality 'social' housing developments may be directed into the lowest quality environments (Liu, 2001). Such discriminatory siting would clearly be labelled as an environmental injustice.

An alternative economic mechanism might also lead to environmental inequalities around an undesirable land use, owing to the fact that the affluent have the financial means to be able to place a higher value on environmental quality (Liu, 2001). Following the deterioration of local environmental quality (whether actual or perceived), selective migration may act as a sorting process. More deprived people are more likely to remain in, or move into, the degraded area because of the cheaper housing and/or increased employment opportunities (Been and Gupta, 1997; Freeman, 1972) and more affluent people are more likely to move away to, or remain in, less degraded areas. Longitudinal studies have shown that area demographics may change over time because of such selective mobility (Brimblecombe et al., 1999; Cox et al., 2007). It would be less simple to categorise this inequality as an injustice, as whether it is fair or unfair is an ethical and political question (Walker et al., 2005).

The nature of the causative mechanism behind environmental inequalities has significant implications for measures aimed at delivering environmental justice, such as those embodied by the Sustainable Development Strategy of the Scottish Government. Thus far, policies aimed at delivering EJ have focused primarily on reducing facility siting in poor and minority neighbourhoods (Lambert and Boerner, 1997). But such policies may be misguided and will result in only short-term equality if housing market dynamics subsequently attract poor or

minority households into the area, re-establishing the former inequality (Lambert and Boerner, 1997).

Environmental inequality and landfill sites

Evidence for environmental inequality with respect to landfill sites has been presented by a number of researchers (Been, 1995; Been and Gupta, 1997; Fairburn et al., 2005; Pastor et al., 2001). In Great Britain communities living in proximity to landfill sites are more likely to be socioeconomically deprived than those living further away (Elliott et al., 2001; Wheeler, 2004).

However, it is unclear how this environmental inequality has arisen. The causative factors leading to environmental inequalities around waste sites have been studied in the US (Been, 1994; Been and Gupta, 1997; Lambert and Boerner, 1997; Oakes et al., 1996; Pastor et al., 2001) but we know of no studies that have investigated the mechanism behind environmental inequalities in the UK.

There is evidence that landfill sites may have a post-siting effect on local communities. Property value effect studies (Kiel and McClain, 1995; Kohlhasse, 1991) and attitudinal surveys (Baxter and Greenlaw, 2005; Furuseth, 1989) reveal that hazardous waste facilities are among residents' least desirable uses for land in the vicinity of their homes. Upon becoming operational, the noticeable pollution from a facility can devalue local property in a short space of time (Kiel and McClain, 1995). A British study found that house prices in Scotland were 41% lower than average in the vicinity (within 0.25 miles) of landfill sites (DEFRA, 2003).

Study objectives

We studied the distribution of landfill sites and their local impacts across Scotland to investigate whether there was evidence of environmental inequality. We first asked whether deprived areas were disproportionately exposed to landfill sites in Scotland. Secondly we asked whether there was evidence that landfill sites had been disproportionately sited in deprived areas (i.e., discriminatory siting hypothesis) or that deprivation had increased following landfill establishment (i.e., market dynamics hypothesis).

Issues of study design

A longitudinal approach is required to evaluate whether deprived areas around a site were deprived pre-siting (suggesting discriminatory siting) or became deprived post-siting (suggesting the effects of market dynamics). Environmental justice research is often criticised on the basis of methodological issues (Bowen, 2002; Mantaay, 2002; Perlin et al., 1995). The appropriate geographical unit of analysis will depend on the environmental hazard being investigated and its likely area of influence (Perlin et al., 1995). Longitudinal analyses are further complicated by the requirement for a geographical unit with consistent boundaries across the study period, as census geography boundaries often change to reflect population changes (Mitchell and Walker, 2006).

Measuring exposure directly is generally unfeasible for large-scale analyses, but the simplifying assumptions used to classify exposure in many studies are inadequate (Mantaay, 2002). Due to resource and knowledge-base limitations, studies tend to assess exposure to landfills on the basis of surrogate measures such as proximity (Vrijheid, 2000). Proximity-based exposure assessment assumes that proximity to an environmentally undesirable site (e.g., landfill) is a measure of exposure to the environmental degradation resulting from the

site (Bevc et al., 2007). At the most basic level some studies assume that exposure to environmental impact is confined to the small area (e.g., census output area) that hosts the site, regardless of whether the site is centrally located or adjacent to boundaries with other areas (e.g., Been, 1995; Been and Gupta, 1997; Lambert and Boerner, 1997; Oakes et al., 1996). This approach is subject to the artificial constraints imposed by the boundaries used. Other studies recognise the exact location of the site and characterise exposed and unexposed areas based on a generally arbitrarily defined distance from the site (e.g., Dolk et al., 1998; Elliott et al., 2001; Fairburn et al., 2005; Pastor et al., 2001; Wheeler, 2004), which assumes that environmental impacts radiate uniformly from the site.

However, disproportionate distribution of environmental hazards does not necessarily equate to disproportionate exposure, as spatial patterns of exposure are considerably more complex than these proximity-based assessments imply. Use of the exposed/unexposed dichotomy implies that a population is either environmentally disadvantaged or not, whereas in reality a continuous exposure gradient will exist. Proximity often does not provide an adequate proxy for exposure, for example if local wind conditions mean that exposure is strongly directional (Briggs, 2005). A landfill site can impact upon many aspects of the environment (e.g., air quality, water quality, noise, landscape); hence exposure pathways will differ depending on the specific aspect under consideration. Airborne emissions from a landfill site, for example, will depend upon site-specific factors including the type and quantity of waste, residency duration of waste, lining and capping materials and presence of gas collection (Bridges et al., 2000; Lewis-Michl et al., 1998). The resulting impact on air quality for surrounding areas will depend on the nature and quantity of emissions and local meteorological conditions, in addition to distance from the site. Improved data availability and the spatial analyses

possible in geographical information systems (GIS) now enable a more sophisticated treatment of ‘exposure’.

METHODS

Overview

We identified Scottish landfill sites and then used an exposure model based on each site’s airborne emissions and local wind conditions to estimate relative exposure in surrounding areas. We explored whether environmental inequalities existed: i.e., were exposure levels significantly associated with area-level deprivation? We also analysed how socioeconomic characteristics of the exposed areas changed over time and how these changes were related to the landfill site, to deduce how environmental inequalities might arise around the sites.

Landfill selection

To maximise comparability of potential environmental effects we selected only landfill sites that are regulated under the European Union’s Integrated Pollution Prevention and Control (IPPC) Directive (Directive 96/61/EC). This directive covers landfill sites that are likely to present the greatest environmental and health risks: those receiving more than 10 tonnes of waste per day or having a total capacity exceeding 25,000 tonnes. Names of IPPC landfill sites were extracted from the Scottish Environmental Protection Agency’s (SEPA) Scottish Pollutant Release Inventory (SPRI) for 2002, 2004 and 2005 (SEPA, 2003, 2005, 2006), yielding a total of 54 sites.

Landfill data collection

Landfill site coordinates were provided by SEPA or obtained by georeferencing site postcodes. The positional accuracy of SEPA coordinates has been found to be subject to considerable error in other studies (Elliott et al., 2001; Jarup et al., 2002), with significant implications for the accuracy of analyses based on proximity to the site. We therefore digitised the boundaries of each landfill site using Ordnance Survey's LandLine product (1:1250) and aerial photography from online mapping services, and derived the geographic centre of each site (average discrepancy of over 300 m, maximum 1583 m).

Site-specific information (e.g., first year of operation, design characteristics that may affect local impact) was obtained from landfill operators during a short structured telephone interview. Using this information we selected the landfills licensed to receive Municipal Solid Waste (MSW), which originates from domestic properties and other residential sites. MSW decomposes to form noxious leachate and gases, hence these sites have greater environmental impacts than sites receiving only inert waste.

Selection of small area geography

To allow longitudinal comparisons using census data and the detection of localised effects (if present) the small area geography was required to be consistent through time, consistent with census geographies and as small as practicable. The Continuous Areas Through Time (CATTs) developed for Scotland by Exeter et al. (2005) provide the smallest possible areal unit for census-based population comparisons between 1981, 1991 and 2001 and were therefore selected for use in this study. This geography consists of 10,058 individual areas with an average population in 2001 of approximately 500 persons (Exeter et al., 2005).

Population-weighted centroids were derived for the CATTs, because these represent the location of the population more accurately than geographic centroids (Luo and Wang, 2003), an important consideration in exposure studies. We calculated population-weighted CATT centroids for 1981, 1991 and 2001 separately, using the relevant OA populations (see Luo and Wang, 2003 for method), to account for the possibility that the population distribution within each area may have changed over time.

Modelling exposure

Migration of landfill leachate into groundwater can be an important pollutant pathway and exposed populations can be identified if people source their drinking water locally or consume locally caught freshwater fish (Vrijheid, 2000), but this is not generally the case in Scotland (Scottish Executive, 2003a). The potentially exposed population would therefore be numerous, widely dispersed and exposure would be difficult to estimate.

We selected air quality impacts for further investigation in this study, as the main risks to human health from landfills are attributable to airborne emissions (Environment Agency, 2004). MSW landfills emit landfill gas, containing a small fraction of hazardous volatile organic compounds (Lewis-Michl et al., 1998), unpleasant odours and dust. We classified the exposure of all CATTs to air quality impacts arising from landfill sites using the technique described below.

Data-intensive plume models are often used to predict air quality impacts around single point sources (e.g., Roberts and Chen, 2006). The data required (e.g., quantities and types of waste landfilled per year, local atmospheric conditions) were not available for the sites in this study; therefore a less complex assessment method was sought. A simple landfill exposure index

incorporating site-specific emissions and local wind conditions was adapted from the emissions modelling work of Buffler et al. (1988) and Pisani et al. (2006):

$$E_j = \sum_{i=1}^P \left[M_i \times \frac{1}{D_{ij}^2} \times S_{ij} \times F_{ij} \right]$$

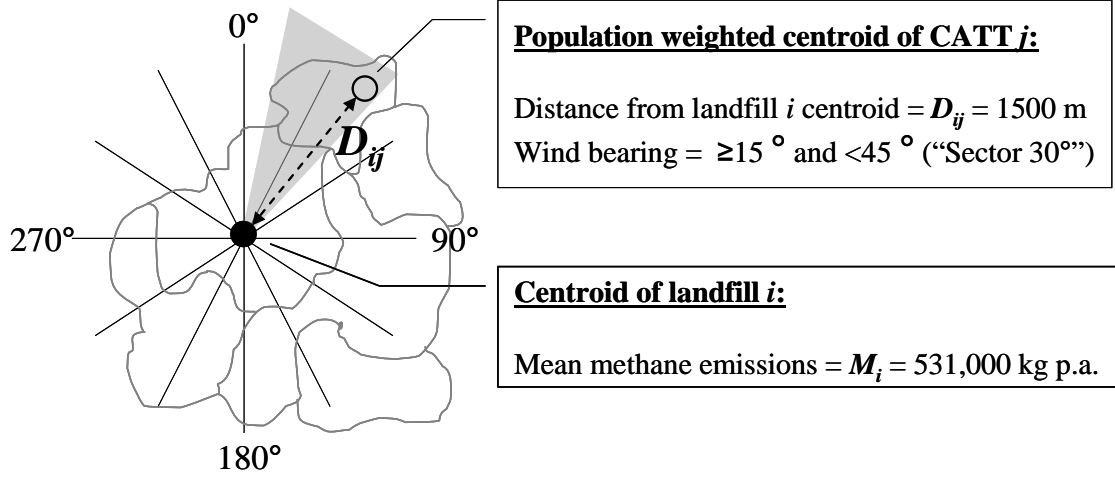
where E_j is the exposure estimate for CATT j , M_i is the annual quantity of emissions from landfill i , D_{ij} is the distance from landfill i to the centroid of CATT j , S_{ij} is the mean wind speed in the direction from landfill i to CATT j , F_{ij} is the frequency of winds that blow in this direction and P is all landfills. Hence a CATT located on a bearing from which winds blow frequently and/or with high mean speed will be more exposed to landfill impacts than a CATT located a similar distance from the landfill but on a bearing from which winds blow infrequently and/or at lower speeds.

The process of calculating exposure scores is illustrated in Figure 1. Average estimated methane emissions for each site (SEPA, 2003, 2005, 2006) were used as a proxy for total landfill emissions because methane typically accounts for 65% of these emissions (DEFRA, 2004; Lewis-Michl et al., 1998). Emissions estimates in the SPRI are usually derived from models (Chris Connor, SEPA Air Quality Specialist, personal communication) as accurate measurement is not possible, but they represent the best data available. Average wind frequencies and speeds (1970 to 2000) in each of 12 30° direction sectors at each landfill were calculated using MIDAS Land Surface Observation data from the closest reliable weather station (UK Meteorological Office, 2007).

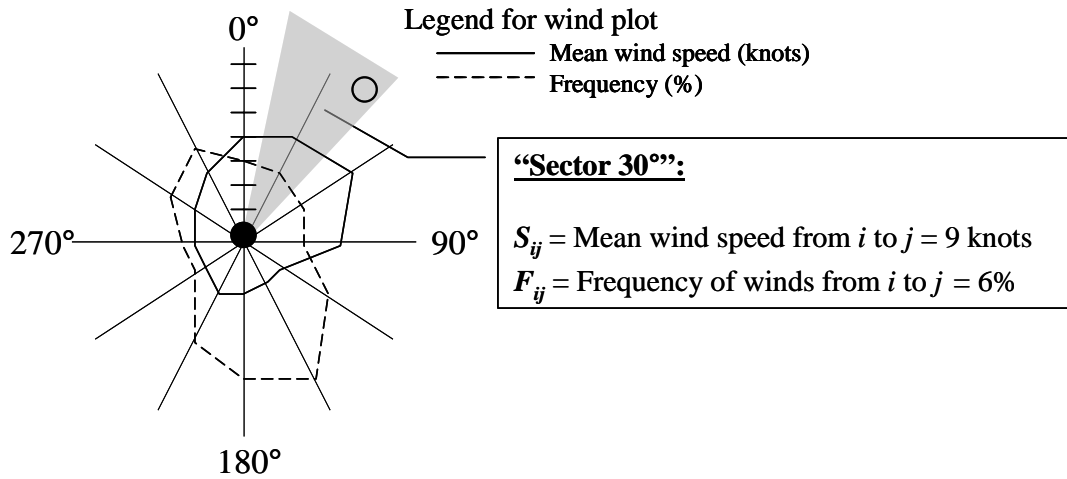
The exposure score, E , was calculated for each CATT for 1981, 1991 and 2001, accounting for all municipal landfills that had begun operations prior to the year in question. This gave a continuous exposure surface across the whole of Scotland which helped circumvent the arbitrary classification of CATTs as simply exposed or unexposed.

Mapping the exposure scores (Fig. 2) highlights some important attributes of this exposure classification method. It can be seen that sometimes the host CATT is not the most exposed (e.g., around landfills 118 and 94), because of the location of its population-weighted centroid (and hence the distribution of its population). Also, depending on site emissions and local wind conditions the boundary between ‘exposed’ and ‘unexposed’ CATTs will be at a non-uniform distance from each site. This is more realistic as it identifies the populations around the landfill that are most at risk of being impacted by the site, rather than assuming that risks are confined to the host CATT, or within a uniform buffer of the landfill.

(a) Determine relative positions of CATT j and landfill i



(b) Summarise local wind conditions



(c) Calculate exposure estimate (E_j) for CATT j

$$E_j = \sum_{i=1}^P \left[M_i \times \frac{1}{D_{ij}^2} \times S_{ij} \times F_{ij} \right]$$

$$E_j = 531,000 \times (1/1500^2) \times 9 \times 6 = 12.75$$

Figure 1. Schematic to show the process of calculating the exposure score, E , for a CATT in the vicinity of a landfill.

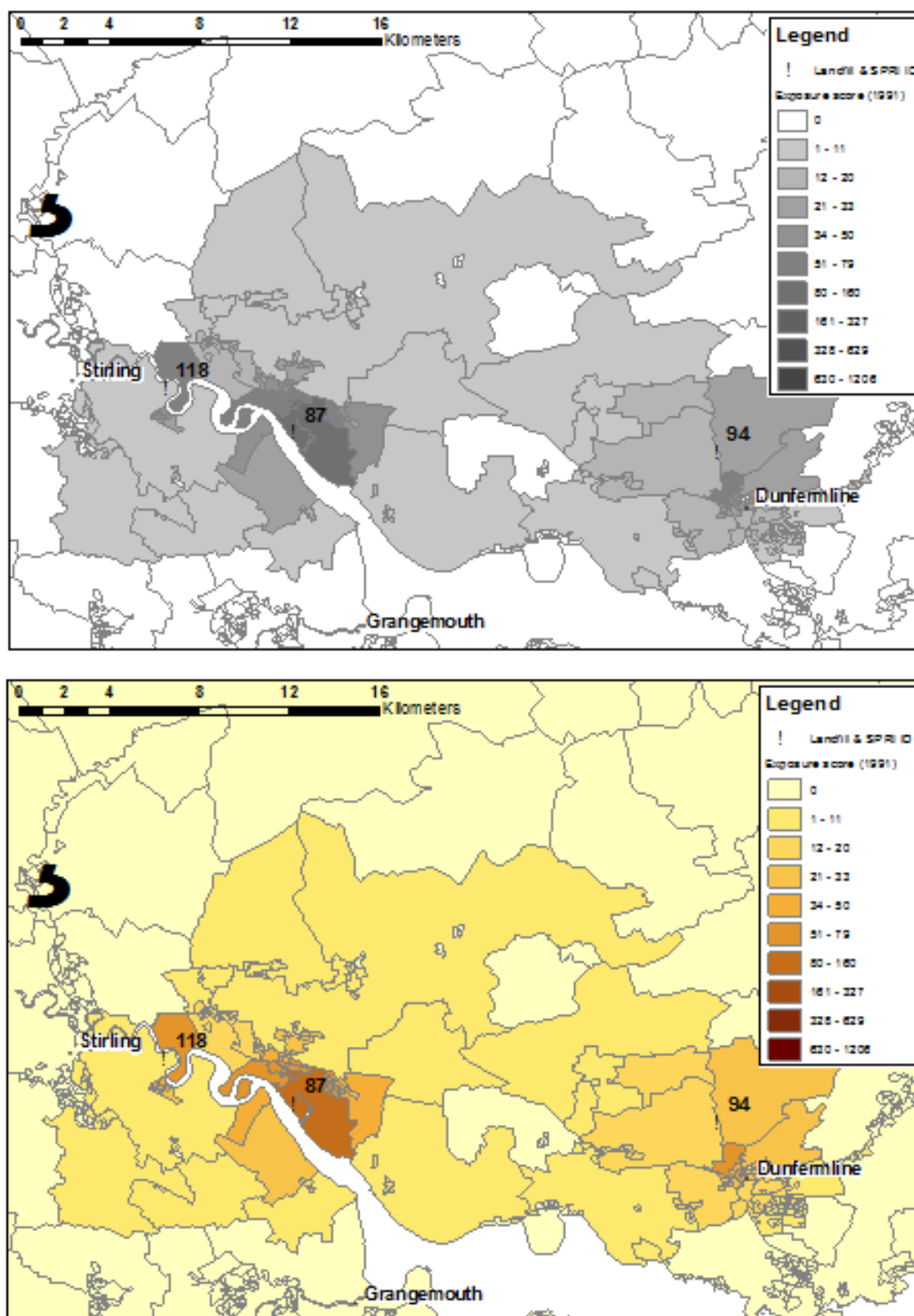


Figure 2. Example of the variation in exposure scores around municipal landfills, shown for three landfills around the Firth of Forth. Boundary data is copyright of the Crown and the Post Office and was provided through EDINA UKBORDERS with the support of the ESRC and JISC. (Colour version included for online publication)

Classifying CATT deprivation

The Carstairs score (Carstairs and Morris, 1989) was used as a measure of small area deprivation, as the scores are widely used and can be calculated for the time span of the study (e.g., Brainard et al., 2002; Exeter et al., 2004; Wheeler, 2004). The more comprehensive Scottish Index of Multiple Deprivation (SIMD) has only been available since 2004. We calculated Carstairs scores for the CATT2 geography for 1981, 1991 and 2001 using relevant census variables. For the purposes of investigating deprivation changes over time we also produced Carstairs scores for 1981 and 1991 that were standardised to 2001 averages, rather than to their specific year.

Questions asked in the 2001 census had changed slightly, affecting the car access and household overcrowding components. In addition to the number of cars or vans being ‘*available for use*’ by the household, the 2001 census included cars or vans that were ‘*owned or available for use*’. The number of rooms used in the calculation of persons per room excluded kitchens ≤ 2 m wide in 1981 and 1991 but included all kitchens in 2001. These changes will affect the direct comparability of the 2001 Carstairs scores with those from 1981 and 1991.

The investigation was Scotland-wide, including both rural and urban areas. As the Carstairs score may have different meaning in rural areas (Christie and Fonea, 2003), the rural or urban status of each CATT (Scottish Executive, 2006) was incorporated in statistical models.

Statistical techniques

Concentration Indices (Wagstaff et al., 1991) were calculated to provide a comparative indication of distributional inequality: how equally exposure to municipal landfills was

distributed across the different deprivation quintiles at each census. The Concentration Index will equal zero if exposure is equally distributed across deprivation quintiles, and will tend towards the extremes of -1 or +1 if exposure is concentrated amongst the most deprived or most affluent quintiles, respectively.

Ordinary least squares regression was used to examine the associations between deprivation and exposure, enabling both variables to be entered as continuous. Logistic regression was used to investigate the mechanism behind environmental inequalities: by estimating the likelihood that a deprived CATT would subsequently become exposed, or that an exposed CATT would subsequently be classified as deprived. Dichotomous deprivation and exposure variables were therefore required. CATTs in deprivation quintile 5 (most deprived) were coded as 1, and all other CATTs as 0. We artificially delineated an ‘exposed’ area as consisting of those CATTs in the top decile (10%) of our calculated exposure scores, as the commonly-used threshold of 4 km (considered by the Environment Agency to be the likely spatial limit of airborne emissions from landfills, Fairburn et al. (2005)) contained approximately 10% of Scotland’s CATTs. CATTs being classified in the ‘exposed’ area for the first time in a particular decade were coded 1 whilst those that remained unexposed and had their population-weighted centroids more than 4 km from any SEPA landfill site (municipal or otherwise) were coded 0 for the models.

RESULTS

Landfill characteristics

A total of 41 municipal IPPC-regulated landfills were identified (Fig. 3). Recently, landfill emissions may have been reduced by gas collection systems and improved construction

regulations, but enquiries revealed that these would not have become effective by the time the emissions data we used were reported. The methane emissions used, averaged over three years, can therefore be considered as relatively representative of previous emissions. Four of the landfills had ceased accepting waste before 2001, but because landfills off-gas for up to 20 years post-closure (Lewis-Michl et al., 1998) methane emissions had still been reported for these sites between 2002 and 2005.

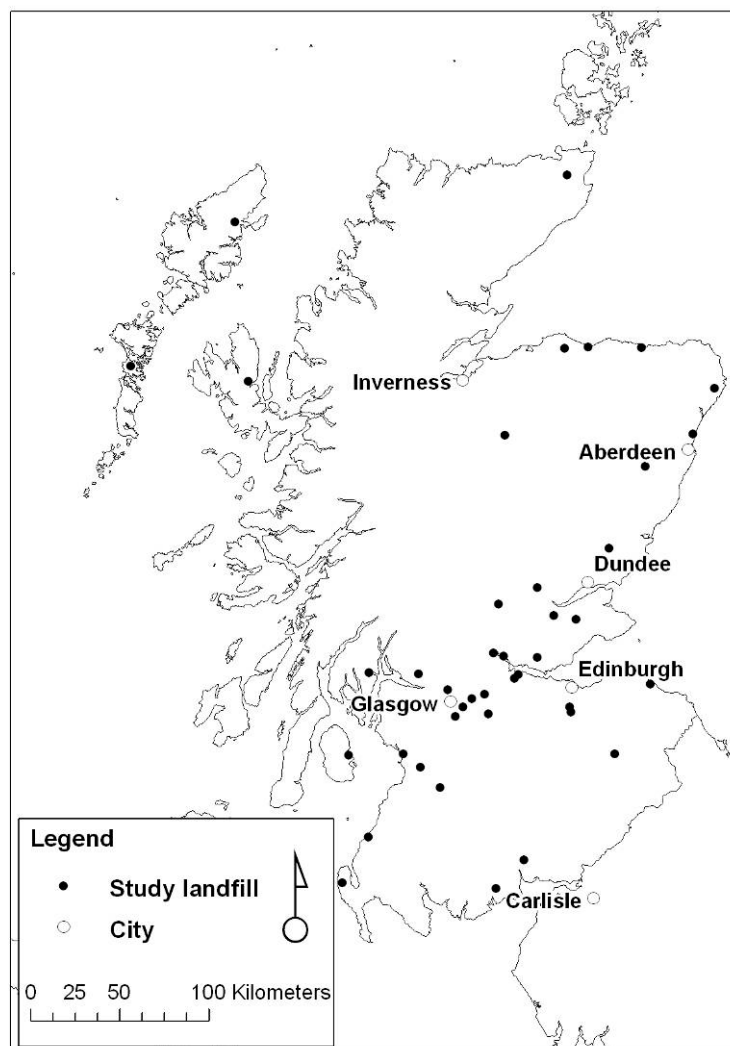


Figure 3. Map showing the locations of the 41 municipal landfill sites identified for the study. Boundary data is copyright of the Crown and the Post Office and was provided through EDINA UKBORDERS with the support of the ESRC and JISC.

Evidence for environmental inequality?

The area defined as ‘exposed’ to a municipal landfill (CATTs in the top decile of exposure scores) accounted for between 10 and 12% of the population between 1981 and 2001. CATTs in the most deprived quintile accounted for the greatest proportion of the exposed population (36%, 30% and 27% in 1981, 1991 and 2001 respectively; Table 1). All Concentration Index values were negative, indicating that exposure to municipal landfills in Scotland is concentrated amongst the more deprived CATTs, although the inequality was greatest in 1981 and least in 2001. In 1981 21% of the most deprived quintile’s population lived in an ‘exposed’ CATT (accounting for 36% of the exposed population), while only 7% of the least deprived did. The exposed population in 2001 (and in 1991 to a lesser degree) was more evenly distributed between the deprivation quintiles, and the lower Concentration Index values reflect this. Inequalities were relatively consistent across the exposure tertiles each year, with the most deprived CATTs accounting for the greatest proportion of the population. The single exception is seen for exposure tertile 1 in 2001.

Ordinary least squares regression was used to examine the relationship between deprivation and exposure to municipal landfills using the continuous scores, enabling a finer level of resolution. After adjusting for rurality and household density, the Carstairs score of a CATT was positively associated with its exposure score ($p < 0.001$), whether in 1981, 1991 or 2001. Analysing the association by deprivation quintile (Table 2) provides evidence that the positive relationship becomes stronger as area-level deprivation increases.

Table 1. Total populations (and percentage by deprivation quintile) living within the area defined as ‘exposed’ (i.e., top decile of the exposure scores) in 1981, 1991 and 2001 by population-weighted deprivation quintiles for Scotland (5 = most deprived). Exposed area has been divided into tertiles (3 = highest exposure score).

Carstairs quintile	Total population	Entire 'exposed' area		Exposure score tertile					
		total	%	1 (lowest)		2		3 (highest)	
				total	%	total	%	total	%
1981									
1	988,829	66,243	11.4	28,589	13.9	18,300	10.2	19,355	9.8
2	988,602	70,408	12.1	27,931	13.6	14,316	8.0	28,161	14.2
3	985,923	85,478	14.7	20,998	10.2	24,499	13.7	39,981	20.2
4	987,578	148,855	25.6	57,173	27.8	58,489	32.6	33,193	16.8
5	987,489	211,592	36.3	70,843	34.5	63,548	35.5	77,202	39.0
Concentration index		-0.25		-0.22		-0.30		-0.24	
1991									
1	981,374	64,595	11.8	30,293	17.6	18,581	10.9	15,721	7.6
2	981,484	94,340	17.2	21,628	12.6	19,569	11.5	53,144	25.7
3	980,848	88,993	16.2	30,196	17.6	26,250	15.4	32,546	15.8
4	982,200	134,798	24.6	34,104	19.9	49,672	29.1	51,022	24.7
5	979,851	166,315	30.3	55,538	32.3	56,796	33.2	53,981	26.2
Concentration index		-0.18		-0.15		-0.25		-0.14	
2001									
1	993,420	53,721	10.6	22,102	13.0	19,870	13.1	11,750	6.3
2	996,961	81,878	16.2	22,818	13.4	16,979	11.2	42,080	22.7
3	989,935	123,379	24.4	50,612	29.8	31,513	20.9	41,254	22.3
4	993,314	108,831	21.5	32,861	19.3	36,509	24.2	39,461	21.3
5	993,353	138,412	27.3	41,556	24.5	46,247	30.6	50,609	27.3
Concentration index		-0.16		-0.12		-0.19		-0.16	

Table 2. Ordinary Least Squares regression coefficients (+ 95% C.I.s) for the relationship between exposure score and individual Carstairs deprivation quintiles (population-weighted) (shown relative to quintile 1, the least deprived), after adjusting for rurality and household density.

Year	Carstairs quintile			
	2	3	4	5 (most deprived)
1981	3.65 (0.18-7.13)*	2.83 (-0.69-6.34)	4.98 (1.40-8.57)*	7.12 (3.27-10.98)**
1991	3.24 (-0.19-6.67)	0.82 (-2.46-4.10)	4.35 (1.07-7.62)*	8.49 (5.12-11.86)**
2001	2.28 (-0.33-4.90)	1.58 (-0.93-4.10)	4.20 (1.79-6.62)*	7.91 (5.52-10.30)**

ns: not significant

* 0.001 ≤ p < 0.05

** p < 0.001

In the models urban CATTs had significantly higher exposure scores than those in rural areas, because municipal landfills must be located close to the population centres they service. As an apparent contradiction, household density was significantly and negatively associated with exposure score. However, this is also understandable because planning and public health strategies are likely to favour siting in less dense areas (Pastor et al., 2001).

Investigating the mechanism behind environmental inequality

The data indicate that environmental inequality exists in Scotland, as deprived areas tend to have greater exposure to municipal landfills than more affluent areas. We then investigated how the inequality may have arisen by asking whether exposed areas were deprived before landfill siting (suggesting discriminatory siting) and/or whether they became increasingly deprived subsequently (suggesting effects of market dynamics).

Evidence for pre-siting deprivation?

Across the study period all deprivation quintiles experienced an increase in their average exposure score (Fig. 4), which was significant in most cases. This is because nine landfills became operational between 1981 and 1990 and eight between 1991 and 2001 (these periods will be referred to as the 1980s and 1990s respectively hereafter). The only significant departure from the mean change across any period was found for the most deprived quintile: exposure score increased significantly between 1981 and 2001 for these CATTs. The results suggest that deprived areas received a disproportionate share of the increased exposure burden over the study period.

Logistic models revealed that the likelihood of a CATT becoming ‘exposed’ in a subsequent decade was significantly associated with deprivation in 1981 but not in 1991. Compared with

the most affluent CATTs (Carstairs quintile 1) all other CATTs were significantly more likely to become ‘exposed’ to a landfill in the 1980s (quintile 2 odds ratio (OR) = 4.09 (1.89 to 8.82); quintile 3 = 6.38 (3.07 to 13.25); quintile 4 = 5.98 (2.83 to 12.64); quintile 5 = 2.55 (1.05 to 6.21)). However, no significant relationship was found for deprivation in 1991. These results provide no evidence that deprived CATTs were disproportionately targeted for landfill siting over the study period, rather they suggest that the most affluent areas were avoided.

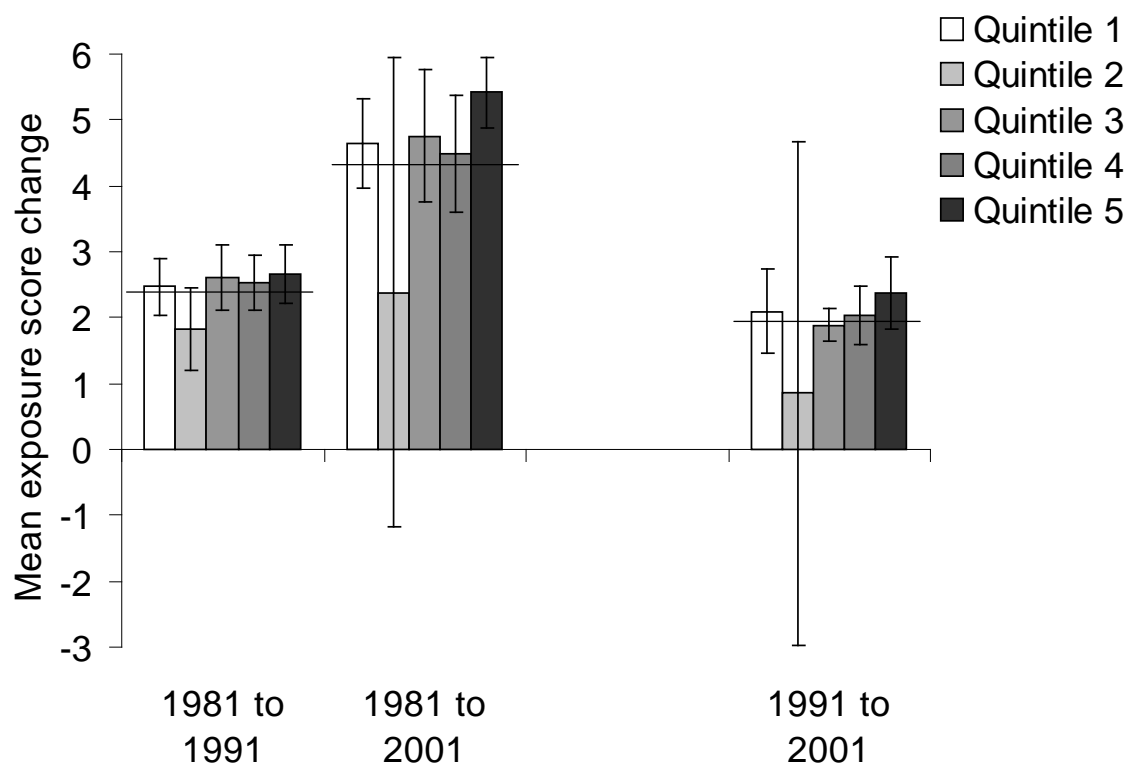


Figure 4. Mean change (and 95% confidence interval) in exposure score across the 1980s and/or 1990s for each Carstairs deprivation quintile (population-weighted) in 1981 and 1991 (with 95% confidence intervals). Quintile 1 is the most affluent and 5 is the most deprived. Horizontal lines indicate the overall mean exposure score change for the period.

Evidence for post-siting deprivation?

A consistent decrease in deprivation scores (2001-standardised) occurred across the study period for all CATTs (Fig. 5), due to increased car ownership and decreased household

overcrowding and unemployment (components of the Carstairs score). Areas that had become 'exposed' to a municipal landfill in the 1980s (treatment CATTs) showed the least improvement (decrease) in their deprivation score on average by 1991 and 2001 (left-hand side of Fig. 5). By 2001 these CATTs showed significantly less improvement in their socioeconomic status than that observed for both control groups ($p < 0.05$). The differences were not found for treatment CATTs that became exposed in the 1990s (right-hand side of Fig. 5).

Figure 5 highlights that the exposed controls (CATTs that had already been 'exposed' to a municipal landfill prior to 1981 or 1991) showed the most marked improvement in their deprivation scores over time: significantly greater than in unexposed controls (all periods) and treatment CATTs (all except 1991 to 2001).

CATTs that had become exposed to a municipal landfill in either the 1980s or 1990s were not significantly more likely to be in Carstairs quintile 5 (most deprived) by the next census, compared to the unexposed controls (1991: OR 1.34 (0.88 to 2.05); 2001: OR 0.96 (0.71 to 1.30)). However, by 2001 the CATTs that had become exposed in the 1980s were significantly more likely to be in Carstairs quintile 5 (OR 1.65 (1.12 to 2.45)). The data therefore provide some evidence that relative deprivation increases after an area becomes exposed to a municipal landfill site, although causation cannot be implied and the effect was restricted to CATTs that became exposed in the 1980s.

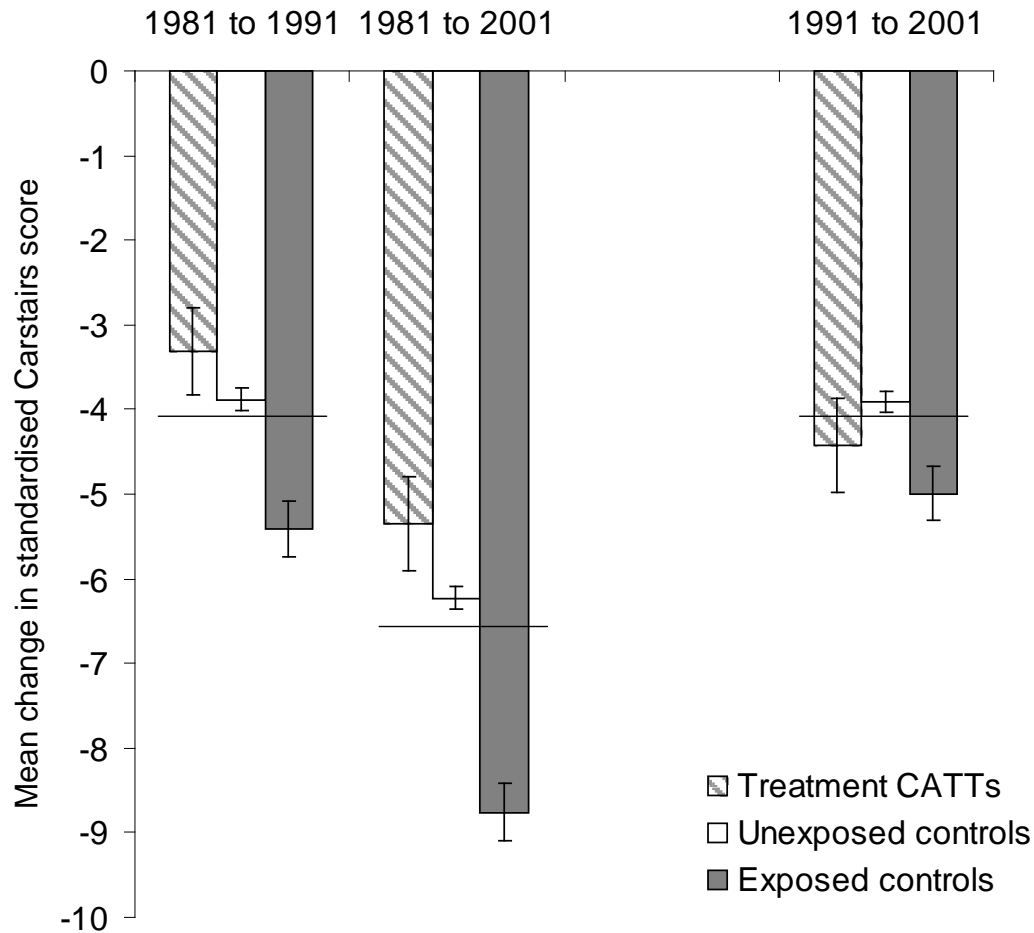


Figure 5. Mean change (and 95% confidence interval) in 2001-standardised Carstairs score across the decade(s) in which the treatment group of CATTs became ‘exposed’ to a municipal landfill for the first time. Carstairs score change is shown for the treatment CATTs, the CATTs that remained unexposed (unexposed controls) and the CATTs that were already ‘exposed’ at the start of the decade (exposed controls). Horizontal lines indicate the overall mean Carstairs score change for each period.

DISCUSSION

Evidence for environmental inequality?

Other UK studies have found environmental inequalities in relation to polluting industrial sites (Friends of the Earth, 1999; Walker et al., 2003; Wheeler, 2004), air quality (Brainard et al., 2002; McLeod et al., 2000; Mitchell and Dorling, 2003; Wheeler, 2004) and living on tidal floodplains (Walker et al., 2003). Exposure to landfill sites has been found inequitable

in England and Wales (Wheeler, 2004) but Fairburn et al. (2005) found no clear evidence that deprived areas were disproportionately exposed to landfill sites in Scotland.

We found clear evidence that deprived populations in Scotland were disproportionately exposed to municipal landfills throughout the study period (1981 to 2001). The most deprived quintile consistently accounted for the greatest proportion of the ‘exposed’ population across the study period. Our focus on the most polluting municipal landfill sites, as opposed to all 224 Scottish landfills, may explain our clear findings compared with the study of Fairburn et al. (2005). The more realistic exposure classification technique developed for this study will also have helped to reveal trends.

Evidence for the mechanism?

We subsequently sought to investigate the evidence for disproportionate siting and post-siting changes as potential mechanisms by which this environmental inequality has arisen in Scotland. Two separate findings suggested that these inequalities may have arisen partly due to inequalities in landfill siting practices over the period. We found evidence that the exposure burden increased disproportionately for the most deprived areas of Scotland between 1981 and 2001. We also found evidence that the most affluent areas were disproportionately avoided when landfills were sited in the 1980s. While discriminatory siting is a possible explanation for the findings they may alternatively be attributable to non-discriminatory siting considerations that our confounding variables have not adequately measured. This important distinction merits further investigation.

The results also suggested that local population changes following the siting of a landfill might have accentuated the environmental inequality, although the results were also not uniform across the period. A pronounced post-siting effect was found for areas that became

exposed in the 1980s: these CATTs were subsequently 1.65 times more likely to be classified as deprived by 2001 than CATTs that remained unexposed. These 1980s-exposed CATTs also showed significantly less improvement in their deprivation scores (standardised to 2001) than all other CATTs (whether exposed or unexposed controls). The results suggest that newly exposed areas were subsequently set on a shallower trajectory of socioeconomic change relative to other areas. High rates of out-migration of the affluent and in-migration of the deprived relative to other areas may explain this finding.

A number of factors may have caused landfill establishment to have a particularly marked effect in the 1980s. Population migration rates within Great Britain as a whole (Dorling and Atkins, 1995) and Scotland (Registrar General, 2006; Scottish Executive, 2003c) were particularly high in the 1980s, and were characterised by movement of middle and upper income households (Scottish Executive, 2003c). Public perception of pollution as being unhealthy and undesirable dramatically increased (e.g., the widely publicised health effects of the Love Canal landfill, NY; Vianna and Polan, 1984) and Lambert and Boerner (1997) suggest that the effects of pollution on land values and residential patterns would be most apparent after this time. An increased desire to live away from pollution sources and the high mobility of the more affluent may have produced the strong post-siting effects we have reported.

Why then were these post-siting changes not found for areas that became exposed to a municipal landfill in the 1990s? One possibility is that landfills that began operating in the 1990s were engineered and operated to higher standards, due to the stringent licensing system introduced with the Environmental Protection Act 1990 (DEFRA, 2003). Furuseth (1989) found that 60% of respondents living within one mile of one hazardous waste facility did not

know that the facility was there, and attributed this to particular siting, landscaping and operational attributes. A sensitively planned and operated landfill might therefore minimise local property devaluation and population change effects.

The results also suggest that area-level socioeconomic status might ‘recover’ following the initial landfill effect. Areas that been exposed to a landfill in a previous decade (exposed controls in Figure 5) experienced a significantly greater decrease in deprivation than unexposed controls and Scotland as a whole. While exposure to a municipal landfill might initially stunt local socioeconomic improvement relative to other areas (see treatment CATTs in Figure 5), this effect may be reversed in subsequent decades as the area ‘catches up’ with other areas. Indeed, studies of house price effects through the life of a landfill suggest that the devaluation effect will be greatest when a landfill is first sited and comes into operation and will then gradually reduce as people adjust to the presence of the landfill (reviewed by DEFRA, 2003). Such a recovery effect could act to reduce environmental inequalities over the life of the site.

Which came first, the deprivation or the landfill?

Our study provides evidence that environmental inequalities around municipal landfill sites in Scotland have arisen due to a combination of pre- and post-siting processes. Put another way, the deprivation may have preceded 1980s-sited landfills to a certain extent, but subsequent local population changes are likely to have accentuated the inequalities. While these trends might be due to inequitable siting processes and market dynamics affected by the presence of the landfill the results are not sufficient to prove causation.

Empirical studies of the causative factors behind environmental inequalities have largely considered toxic waste facilities in the US, and the evidence is inconsistent. Evidence that

these facilities have been disproportionately sited in areas with deprived and/or minority populations has been presented by Been (1994), Been and Gupta (1997) and Pastor et al. (2001). Evidence that deprived and/or minority populations have increased around these facilities post-siting has been presented by Been (1994), Lambert and Boerner (1997), Been and Gupta (1997) and Baden and Coursey (2002).

Been (1994) extended two of the key EJ studies in the US and found evidence for both mechanisms. Bullard's (1983) sample of waste sites in Houston had not been disproportionately sited but increasing poverty and percentage minority composition was subsequently experienced in the populations around the sites (attributed to the demographic phenomenon referred to as 'white flight'). In contrast, her reanalysis of the GAO's (1983) sample of waste sites in south-eastern US revealed that the sites had been disproportionately sited in areas with higher than average poverty and minority populations, and were associated with a decline in minority populations post-siting. The available evidence therefore suggests that there is no single dominant mechanism by which environmental inequalities might arise. The relative importance of pre-siting and post-siting processes seems likely to vary on a case-by-case basis, and through time (as suggested by the present study).

Policy implications

The planning process in Scotland has been considered by many as being remote and stacked in the interests of developers (Scandrett, 2007). The previous Scottish government committed to securing 'environmental justice for all of Scotland's communities' (Scottish Executive, 2003b). Strategic Environmental Assessments (SEA) are now required for new developments such as landfill sites, and require that the effects on population and human health, among other environmental aspects, are assessed (Environmental Assessment

(Scotland) Act 2005). While such assessments may help to prevent environmental inequality in the siting process they are unlikely to prevent inequalities developing as a result of post-siting processes, such as those suggested by our study. For this reason it is crucial that policies designed to address environmental inequality should be informed by evidence regarding the causative processes (Lambert and Boerner, 1997).

Study limitations

Methodological limitations were imposed on the study by the nature of the available data. The results were derived from population and not individual characteristics which can lead to ecological fallacy issues, in which population level associations may not be operating at the individual level (Guthrie and Sheppard, 2001). Area-based analyses may also be subject to the Modifiable Areal Unit Problem, in which the size and shape of the areas can influence the results (Openshaw, 1984). While these issues must be considered when interpreting the results; the selection of as small a unit of analysis as possible will have helped to keep these effects to a minimum.

While the study attempted to predict exposure as realistically as possible, it should be noted that issues still remain with this technique. Exposure should relate to individuals not areas, as this will most adequately reflect their risk of adverse health outcomes. The actual exposure of individuals in a particular area will depend on what proportion of their day they spend in the area.

Additionally, all studies of this nature require a distinct spatial and temporal threshold between unexposed and exposed, which necessarily imposes some artificiality onto the more continuous real-world situation. When necessary we defined our ‘exposed’ area using

exposure scores, which took account of important inter-site differences in emissions and wind conditions, differences that would be overlooked if a uniform buffer had been applied.

Many factors unrelated to exposure to landfills may affect deprivation changes. The study was not able to control for all possible influential factors, and hence the results cannot be conclusively attributed to landfill sites. Proximity to other undesirable land uses might influence siting decisions and affect deprivation in an area but insufficient data were available to study these effects. Many landfills occupied land previously used for quarrying, which may have had a prior effect on deprivation locally, but there were insufficient control cases (i.e., landfills situated in more pristine areas) to permit an investigation of the possible differences. If anything, inability to control for these factors will have reduced the sensitivity of the analyses to identify significant results.

Future work

Finding disproportionate *exposure* to poor environmental quality is only part of the concern. Showing the disproportionate *effects* of poor environmental quality should be the crucial next step (Mantaay, 2002). A number of studies give evidence that implicates landfill or waste treatment sites in increased risk of congenital anomalies, low birth weight births, cancers, respiratory illness and self-reported health symptoms in the surrounding areas (e.g., Dolk et al., 1998; Elliott et al., 2001; Lipscomb et al., 1991; Pukkala and Pönkä, 2001; Shaw et al., 1992; Vianna and Polan, 1984; Vrijheid, 2000). Patterns of area-level health outcomes in relation to exposure to municipal landfill sites in Scotland will be explored in a separate paper.

The need for consistency in census questions and small-area geography restricted our study period to 1981 to 2001, but it would be informative to be able to study siting processes and deprivation changes for previous decades, as these will have produced the marked inequality observed in 1981. The market dynamics hypothesis could be investigated further using house price data across the period.

Conclusions

Few studies have assessed the mechanism behind environmental inequalities directly, and we know of no UK studies that have done so. The present study addressed this shortcoming for Scotland. We used spatial data and analyses to improve upon the exposure classification techniques used in many other studies of environmental inequality, thereby incorporating an additional degree of realism. We demonstrated that there is strong evidence for environmental inequality in Scotland: deprived areas are disproportionately exposed to municipal landfills. Evidence for the causative mechanism was less clear, but the results suggest that both disproportionate siting and post-siting market dynamics may play a role. With reference to the initial question we posed we find that there is no simple answer: area deprivation may have preceded landfill siting to some extent, particularly in the 1980s, but landfill siting preceded a relative increase in deprivation (i.e., a reduced improvement in socioeconomic status in exposed areas). Further research is needed before the causes can be firmly identified and addressed.

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